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EXPERIMENTAL STUDIES OF THERMAL CONTACT CONDUCTANCE BETWEEN COPPER, STAINLESS STEEL AND ALUMINUM SAMPLES USING A SETUP DEVELOPED AT ALBA SYNCHROTRON LIGHT SOURCE

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Abstract

Accurate knowledge of the Thermal Contact Conductance (TCC) between surfaces is of great importance for the design of components in particle accelerators, such as mirrors, monochromators, filters, detectors, among others. The TCC depends on many variables such as surface finish, type of material, pressure between samples, temperature and interface materials. The TCC can be found in specialized literature, but it is not always possible to find this information for all applications. This forces the design engineer to assume conservative or optimistic values that can result in over or under sized designs. In this context, an experimental setup has been developed in the Engineering Division of ALBA to evaluate thermal contacts under ambient and cryogenics conditions, in vacuum and for different pressure ranges between samples. This work presents the latest experimental results obtained for sample combinations of Copper, Stainless Steel and Aluminium materials.

INTRODUCTION

Thermal contact between surfaces, known as Thermal Contact Conductance (TCC), has been extensively studied in the field of engineering due to its importance in the design and optimization of thermal systems [1-4]. In particular, within the field of particle accelerators, TCC values are employed in the design of optical components for experimental beamlines, among other applications. At the ALBA synchrotron, TCC values obtained from the specialized literature have been used for the design of mirrors and monochromators.

However, suitable values have not always been available for all designs, which has led to the adoption of conservative assumptions. Specifically, for the design of ALBA third-generation components, conservative values of 2000, 6000, and 10000 W/m^{2}K have been assumed for thermal contacts considered poor (dry contact), average, and good, respectively. Similar approximations have been reported by [5] for the design of monochromators at the ESRF synchrotron. While these conservative estimates have ensured proper component performance, in some cases they have resulted in over-dimensioned systems.

This issue becomes more critical under higher power densities and net power loads, as expected in the new operating conditions of ALBA II [6], an ongoing project to upgrade ALBA to a fourth-generation synchrotron. In this context, a review of TCC values is of particular importance in order to optimize optical components design and avoid unnecessary oversizing.

To address this need, the ALBA Engineering Division has developed its first experimental setup designed to measure TCC under both ambient and cryogenic conditions [7], with recent results presented in this work.

EXPERIMENTAL SETUP

Figure 1 shows the main components of the experimental setup, while Fig. 2 displays the main parts of the components located inside the vacuum chamber. The system consists of a vacuum chamber, inside which the samples under investigation are placed. The chamber is connected to the vacuum pump system (primary and secondary), which allows thermal isolation of the samples inside the chamber, reaching pressures as low as 10^{-6} mbar. The lower part of the chamber, where the cold finger is located, is connected to a water chiller that maintains a constant temperature of 23ºC. For cryogenic experiments, the chiller is replaced by a liquid nitrogen Dewar, enabling temperatures as low as 80 K.

Power applied to the heaters located in the heating block is regulated via control and data acquisition units, generating average power values of approximately 40 W. At the top of the setup, a load cell has been installed to regulate the force applied to the samples through a spring system; this component controls loads of up to 500 N. The acquisition units monitor relevant experimental variables, including temperature measurements from 10 sensors placed on the two samples and on the internal walls of the chamber, vacuum pressure values, and load applied to the samples. The water chiller features its own regulation system, enabling self-control of water flow and temperature.

Thermal isolation of the samples, cold finger, and heating block from the upper and lower parts in contact with the vacuum chamber is achieved by means of two PEEK blocks.

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Figure 1: Main components of the ALBA experimental setup for the study of thermal contacts.

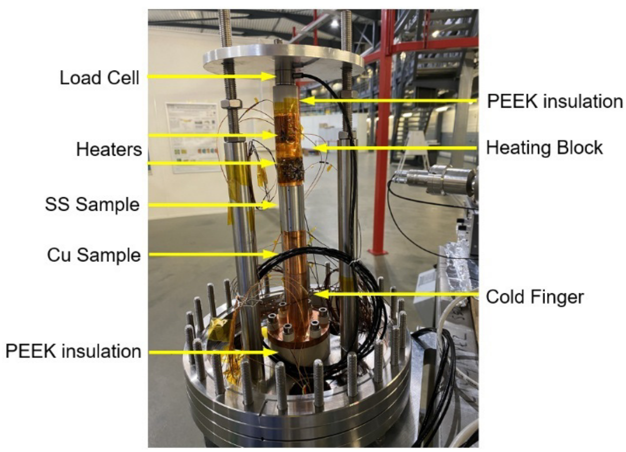

Figure 2: Main components located inside the vacuum chamber (specific case for the study of Stainless Steel and Copper samples).

EXPERIMENTAL RESULTS

TCC values have been calculated following the generalized approach described in [8]:

$$TCC = \frac{Q/A}{\mathrm{T1}-\mathrm{T2}} \tag{1}$$

Where T1 – T2 is the temperature discontinuity at the interface, and Q/A is the heat power per unit area flowing across the interface.

For each case, five repetitions were performed, resulting in a total of 55 experiments. Combinations of polished samples of Copper (Cu), Stainless Steel (SS), and Aluminum (Al) were studied under both ambient and cryogenic conditions, using dry contact and applying Indium foil at the interface. The duration of the experiments was approximately 2.5, 3.5, and 4.5 hours for the Cu–Cu, Al–Cu, and SS–Cu cases, respectively, under dry contact and ambient conditions. The longest experiment, lasting 6 hours, corresponded to the SS–Cu case under cryogenic conditions

Figure 3 presents the experimental results for the Cu–Cu case, studied under ambient conditions and at applied pressures of 0.19, 5.3, and 10.4 bar. Under the same conditions, sample combinations of SS–Cu (Fig. 4) and Al–Cu (Fig. 5) were also investigated. The maximum values of the relative standard deviation (RSD) obtained were 2.7%, 3.6%, and 1.9% for the Cu–Cu, SS–Cu, and Al–Cu cases, respectively.

For the lowest applied pressure (0.19 bar) – corresponding to the combined weight of the upper sample, heating block, and load cell – the highest thermal contact conductance was obtained in the Cu–Cu case (3230 W/m^{2}K), while the lowest value was observed for the SS–Cu case (294 W/m^{2}K). The Cu–Cu results confirm that the previously assumed conservative value of 2000 W/m^{2}K for dry contact at ALBA is indeed very conservative. In contrast, the SS–Cu results indicate that the assumed value is overly optimistic – a practical application example is found in special thermal couplings using copper braids.

In Fig. 3, the experimental results are compared with data from reference [9]; the largest deviation (28%) occurs at the lowest pressure (0.19 bar), whereas at 5.3 and 10.4 bar, the differences in thermal conductance are around 5.3% and 2.3%, respectively.

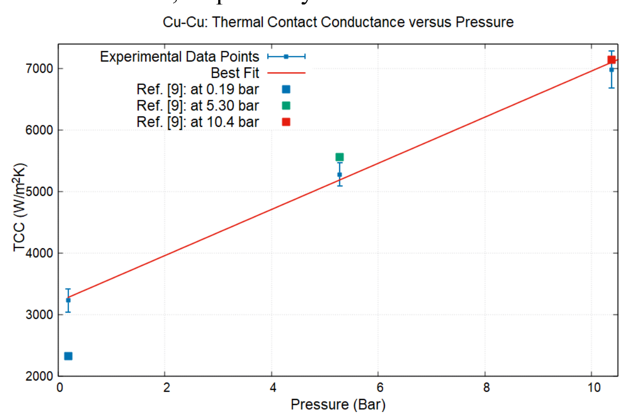

Figure 3: Thermal conductance for Cu–Cu samples under dry contact and ambient conditions. Three data points from reference [9] for polished Cu samples are included.

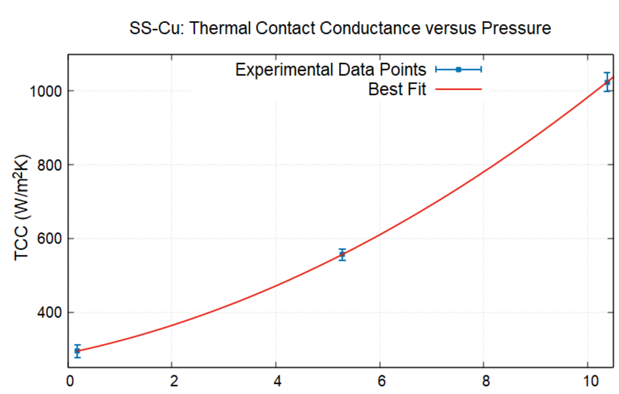

Figure 4: Thermal conductance for SS–Cu samples under dry contact and ambient conditions.

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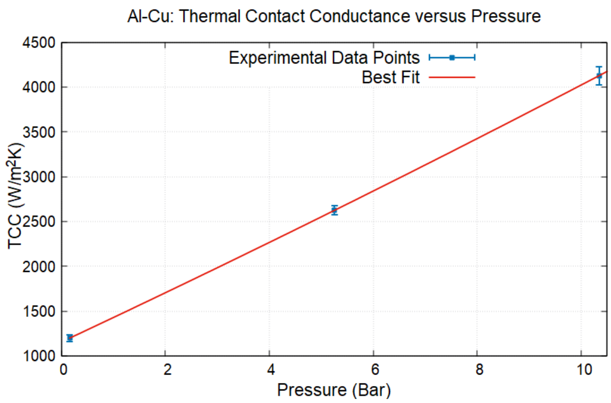

Figure 5: Thermal conductance for Al–Cu samples under dry contact and ambient conditions.

Table 1 compares the results for the SS–Cu case under ambient conditions, for interfaces with dry contact versus Indium foil, both at a pressure of 5.3 bar. The effect of the Indium foil is highly significant, increasing the TCC value by a factor of 169.

Table 2 compares the results for SS–Cu under ambient (23°C) versus cryogenic (81 K) conditions. Both cases involve dry contact interfaces under a pressure of 5.3 bar. Thermal contact conductance under cryogenic conditions is reduced compared to the ambient temperature case.

Table 1: Results for the SS–Cu Case Under Ambient Conditions and a Pressure of 5.3 Bar

	Dry Contact	**Indium Foil**
TCC (W/m^2K)	556	94051
RSD (%)	1.06	5

Table 2: Results for the SS–Cu Case Under Dry Contact Conditions and a Pressure of 5.3 Bar

	Ambient [23ºC]	**Cryogenic [81 K]**
TCC (W/m^2K)	556	345
RSD (%)	1.06	8.4

CONCLUSION AND FUTURE WORK

New results from the ALBA experimental setup for the study of thermal contacts are presented in this work. The samples studied correspond to common engineering materials: Copper, Stainless Steel, and Aluminium.

The studies were conducted under ambient temperature (23ºC) and cryogenic (81 K) conditions, over a pressure range up to 10.4 bar, and for both dry contact and Indium foil interface conditions.

The results for the Cu–Cu case were compared with a similar experiment reported in the specialized literature, showing similar values and/or the same order of magnitude between both studies.

Future work, including detailed characterization of the surface roughness of the samples as well as the automatic regulation of cryogenic temperature, will be key to optimizing the experimental setup.

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